DEPARTMENT OF THE NAVY

BUREAU OF YARDS AND DOCKS

CONTRACT NOy-12561

Interim Report

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Hydrodynamics Laboratory
Hydraulic Structures Division
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I. GENERAL

Change Order "O" to Contract NOy-12561, under which the Laboratory is now operating, provides as a general objective the investigation of the forces and pressures exerted by waves on fixed plane barriers inclined at any angle to the sea surface, and on stepped or off-set plane barriers. In keeping with this objective, the Laboratory is endeavoring to develop a program which will combine a basic investigation of the mechanics of wave-induced forces with the production of immediatly useful data. It is expected, for instance, that the results of experimental force and pressure measurements on plane barriers, aside from their scientific value, can be used with profit in calculating the stability of gravity-type or caisson breakwaters against sliding and overturning.

Since this program represents a new field of work for this Laboratory, the initial portion of the contract period has been devoted to the alteration of existing laboratory equipment, and the design and construction of required new equipment. In all of the modification and development of force and pressure measuring equipment, an effort has been made to design for maximum flexibility. Thus, the resulting basic units can be easily adapted to the various specific phases of the current or future investigations, such as breaking and non-breaking wave conditions, and many configurations of structures for which force or pressure data will be of interest. At this time, all equipment for the pressure measuring and orbit investigation programs has been completed, and work on these programs has begun. The force measuring apparatus is under construction, with completion estimated as June 1, 1953.

In view of the considerable investment in time and funds made to equip the Laboratory for this new type of investigation, this report has been prepared to describe in some detail the alteration of existing equipment and the development of new equipment.

II. EQUIPMENT FOR THE MEASUREMENT OF PRESSURE DISTRIBUTION

The Laboratory was equipped with a channel which was four feet wide by 120 feet long. Studies, previously reported on, had been conducted in this channel requiring a water depth of one foot. To provide for a larger scale of experiment, the 41 feet farthest from the wave machine were removed and the remaining sections were increased one foot in height to a total of three feet in order to permit a still water depth of two feet. Approximately 38 feet from the wave machine a transition, $28\frac{1}{2}$ feet long, was begun such that by means of inner walls laid out on reverse curves a channel width of one foot was achieved. This width was continued for 41 feet. For the first 35 feet three-foot high walls were built of 12-gage steel plate and the last six feet consist of one-half inch tempered plate glass. Provisions were made to close off the glass section by means of the "breakwater" or bulkhead. An overall view of the channel showing the transition is given in Fig.1.

A mechanical wave machine of the inverted ballistic pendulum type, described in previous reports, will be used. It was necessary to raise the pivots of the machine one foot and likewise to extend the wave blade one foot. Waves three inches in height will be generated which upon leaving the one-foot wide end of the transition will have a height of six inches in accordance with the wave energy relation, $E \propto bH^2$ where b equals the width of the segment of wave crest and H the height of the wave, crest to trough. This height will be doubled again due to reflections so that a one-foot high standing wave will bear against the bulkhead.

The bulkhead is designed to fit between the two plates of glass as shown in Fig.2. Four supporting frames have been built to which the three-quarter inch thick aluminum bulkhead may be bolted, providing 90°, 75°, 60°, and 45° slopes. The 90° bulkhead with the appurtenances can be seen in detail in Fig.3.

Holes were drilled through the bulkhead along its vertical center line. These holes have a diameter of one-eighth inch on the seaward face. They are large enough and tapped on the backside to accommodate adaptors for quarter-inch tubing. The spacing of the openings is as follows: Eight on two-inch centers beginning two inches from the floor, followed by openings on 1-1/4 inch centers. The bottom opening, No.0, is connected to the datum pressure element, one of four Statham pressure transducers having a range of 0.3 psi $\pm$, and will register variation in pressure at all times. The other openings are connected to the pressure elements through manifolds. To illustrate: openings Nos. 1, 4, 7, 10, 13, 16, 19, 22, 25, and 28 are connected to the bottom manifold which transmits any pressure variation to one pressure element. The other openings are connected similarly through the other two manifolds to the other two elements. Obviously, the three manifolds will be open only to one opening each at a time, so that the pressure at every third opening and at the bottom opening will be recorded against time. The elements are mounted at the height of the mean water level. The electrical signals from the pressure elements will be recorded as functions of time on a Heiland recording oscillograph.

In a system such as this it is important to remove completely all the air which might be entrapped in order to be able to measure the rapidly changing shock pressures due to breaking of waves as will result when the breakwaters will be inclined. Water will be added through the funnel, forcing out any air in the tubing or in the manifolds. The manifolds are located slightly higher at their far ends, as viewed in Fig.3, and the air will escape through valves installed for this purpose. Finally, air will be expelled from the elements through a bleed hole provided by the machine shop of the Hydrodynamics Laboratory.

Records of wave height will be obtained by use of two submergence elements, one as close to the bulkhead as feasible, the other spaced away from the bulkhead, the distance varying with the wave length. These elements will be connected to the oscillograph to record the variation in the water surface. While these two elements are of the same type as others used for a long time in the Laboratory, considerable experimentation was necessary to adopt the principle to this application, since the required length of the probes is from 18 to 25 inches.

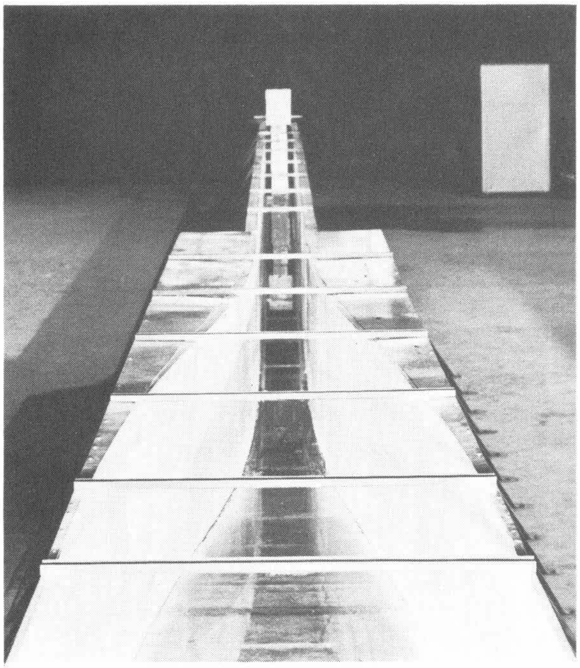

Fig. 1 - Channel transition

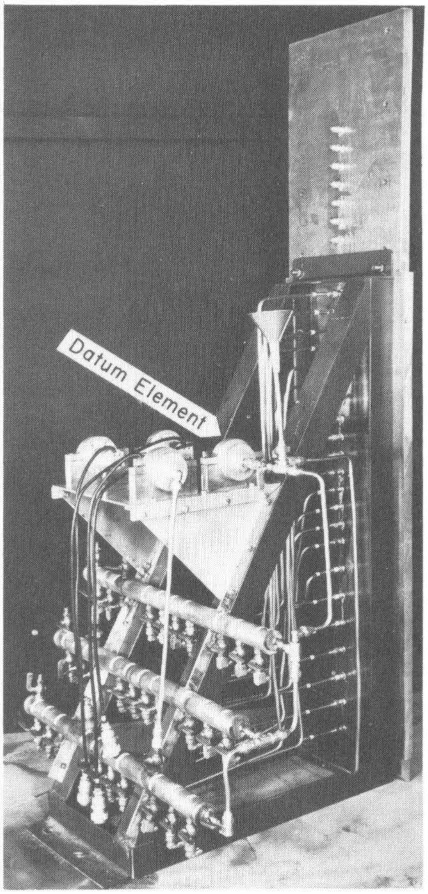

Fig. 3 - Instrumented bulkhead

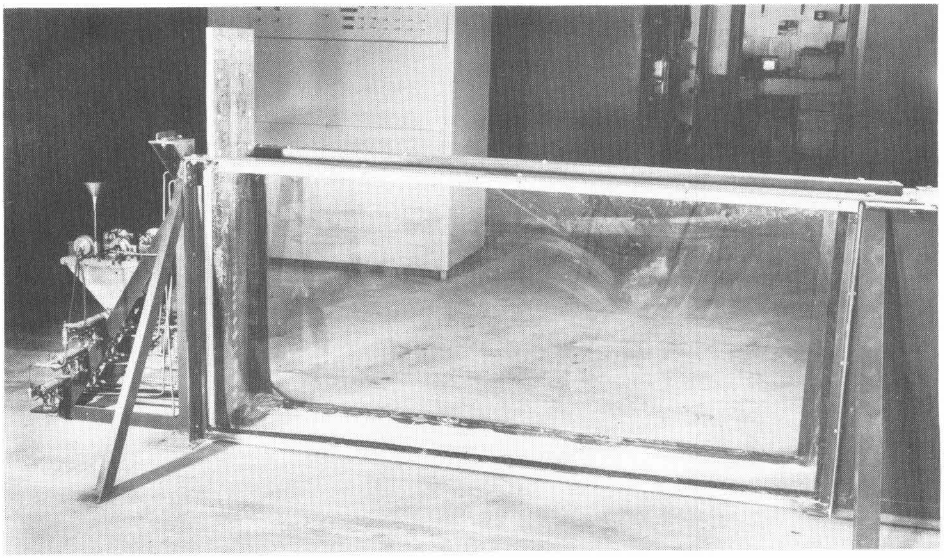

Fig. 2 - General arrangement for pressure distribution measurements

The pressure transducers mentioned above lend themselves well to the measurement of pressure-time relationships for the range from static pressure to pulses of a few milliseconds duration. The transducing element is of the low mechanical energy, unbonded strain gage type, requiring no associated cantilever beams to be stressed with the strain sensitive wires. Pressure applied to the bellows is translated into an exact electrical equivalent by means of a full bridge transducer based on the unbonded strain wire principle. These pressure transducers have a fairly high natural frequency, 220 cps. However, it is possible that their frequency response may not be adequate to follow pressure transients characteristic of breaking waves and it may become necessary to use other devices. The suitability and availability of such instruments is currently being explored.

It is expected that the experiments pursued with this equipment will provide a solid experimental basis for the evaluation of existing and any proposed theories of wave pressure distribution.

III. MEASUREMENT OF TOTAL FORCES AND MOMENTS

A progressive two-dimensional wave in general exerts on a marine structure a force normal to the surface of the body, and an overturning moment. A complete analysis of the action of the wave on the structure must involve the separate determination of this moment and the vertical and horizontal components of the force. Experimental measurement of these three elements will be made in the Laboratory's two-foot wide flume by means of a force balance which has been designed and is now being built. It will then be possible to correlate results with those obtained by use of the pressure distribution equipment previously described.

A schematic diagram of the force balance is shown in Fig. 4. It is a self-contained unit constructed almost entirely of aluminum, which may be conveniently hoisted from the channel when it is desirable. All parts, including the outer box which holds the balance, are designed for a high degree of rigidity, to eliminate for all practical purposes motion anywhere in the equipment except at the points where the forces are measured, and to make the period of natural vibration of the system as short as possible. The balance proper consists of two aluminum castings, one inside the other, mounted relative to each other and to the channel by means of two horizontal and two vertical membranes, with the barrier cantilevered ahead of the balance proper. Forces are measured by means of Statham force transducers which have a capacity of 200 pounds with a corresponding maximum deflection of 0.0015 inch, and a continuous oscillograph record will be made.

The membranes are of 0.025 inch aluminum sheet, mounted concentrically at diameters of 4" and 8". According to the theory of deformation of sheets, the spring constant of these diaphragms is much lower than that of the force elements. The restraining force set up in each membrane by deflecting the inside mounting 0.0015 inch with respect to the outside is less than one per cent of the force measured by the force elements with that amount of motion. A test jig was built with the same dimensions to confirm this fact, and to determine the effect of radial loading on the action of the diaphragms. It was found that radial loads much higher than those which will be imposed on the membranes of the force balance caused no non-linearity of response even over a larger range of deflections than those which the balance will experience.

As Fig.4 indicates, the outer or lift frame is mounted relative to the channel by means of two horizontal membrances, M_1 and M_3. These membranes permit freedom of vertical motion within the 0.0015 inch range of the strain gage, which can then measure the vertical force component within about one per cent. At the same time these diaphragms prevent either horizontal or rotational motion of the lift frame with respect to the channel.

The inner or thrust frame is similarly mounted relative to the lift frame by means of two vertical diaphragms, M_2 and M_4 which permit 0.0015 inch horizontal motion without any vertical or rotational motion relative to the lift frame, and the horizontal component of the force can thus be separated out. It should be pointed out that in theory it is necessary to measure only one component of the force, since the resultant force will be normal to the barrier, neglecting surface friction. Measurement of the second component will, however, provide a cross-check and insure more dependable results. At the same time the versatility of the balance is increased, in that it may in the future be used to measure force components and moments on structures which have a more general surface form that that being investigated in the present experiment. Another potential use of the balance might be to measure friction coefficients of model rubble-faced breakwaters.

The structure supporting the barrier is mounted on the thrust frame through a flexural pivot bearing which is very rigid laterally but which has an extremely low torsional spring constant. The rotational motion of this structure about the pivot is restrained by a strain gage anchored to the end of the thrust frame. This gage records the force at a known distance from the pivot, and thus measures the moment. Knowing this moment and the resultant of the two force components, the location on the barrier of the center of pressure may be immediately determined in terms of the perpendicular distance from the pivot to the action line of the force.

Four separate barriers will be used, inclined at 45°, 60°, 75°, and 90°, respectively, to the horizontal. Only a central section one foot in width will be supported by the force balance with dummy sections on either side to close off the channel. The active section will be sealed with neoprene tape to the bottom of the channel and to the dummy sections of the barrier on either side. Any initial force on the moment element resulting from the cantilevered weight of the barrier will be neutralized by means of very soft springs attached to the channel. These springs will support the weight of the barrier without offering resistance to any motion the transducers permit.

The experimental procedure will consist of generating waves of known parameters by means of the 3/4 h.p. inverted ballistic pendulum type wave machine and observing the time variation of forces and moments at the barrier, and particularly their maximum values before re-reflection from the wave machine blade occurs. These experimental data will be compared with the forces predicted by theory, principally that of Sainflou,[1][2] and with total forces determined by integrating over the face of the barrier the pressures measured in the pressure-distribution experiment.

A future continuation of this force-measuring program will be the measurement of forces due to breaking waves. There is at present no theory available to predict such forces, other than the semi-empirical method of Bagnold and Minikin[3]. The experimental equipment and procedure will be similar to that just described, except that the bottom will be shoaled somewhat to make the waves break at the barrier.

IV. WATER PARTICLE VELCCITIES AND ACCELERATIONS

The classical analysis of water wave motion has led to particle orbit equations on which a great deal of hydrodynamic theory is based, particularly expressions for the inertia and drag forces on marine structures exposed to wave action. To date, little experimental work has been done specifically to verify these equations. An interim project has therefore been initiated to record photographically and to study the orbital motions of the particles, and particularly to determine experimentally orbital velocities and accelerations.

Particle motion may be photographed by placing in the water a globule of material of the same density as the water. This globule must be large enough and white enough to be readily discernible on a photograph, and yet small enough compared to orbit dimensions to behave as a molecule rather than as a solid body. For the purpose of this study a particle diameter of 1/32 to 1/16 inch has been determined to be the desirable size.

The material which has been found most satisfactory for this purpose at this Laboratory is a mixture of Alkazene 47 and heptane, with zinc oxide added for whiteness. The specific gravity of the mixture may be regulated by adding a few drops of heptane to lighten it or Alkazene 47 to make it heavier. Droplets of this material will be added to the two-foot deep water by means of a hypodermic syringe, Fig.5, which discharges through a long, fine metal tube with a tip having an internal diameter of 0.024 inch at an adjustable depth below the surface, in the center plane of the channel.

Multiple exposure photographs using stroboscopic lights will be taken at rates of 20 to 50 exposures per second in a light-free shed, Fig. 6, built over the channel. Using waves of known parameters, a sequence of exposures covering one complete cycle of orbital motion will be taken before any reflections interfere with the primary waves. Quantitative measurements may be made from these photographs by reference to a previously-taken photograph of a rectangular grid located in the center plane of the channel, taken with the camera set in exactly the same location as for the multiple-exposure pictures. The positive location of the camera is made convenient by the use of a special mount which rests on the floor and is fastened to the channel by two rigid struts.

The method of analyzing the multiple-exposure photographs will be to plot the horizontal and vertical components of particle displacement, as determined from the grid photograph, against time, and proceeding to develop velocity acceleration curves. The slope at a point on the X-displacement curve, for example, corresponding to any given time will be the X-component of velocity at that instant, and these velocities may be plotted against time. Similarly, the components of acceleration are determined by measuring the slopes of the velocity curve at specific instants of time.

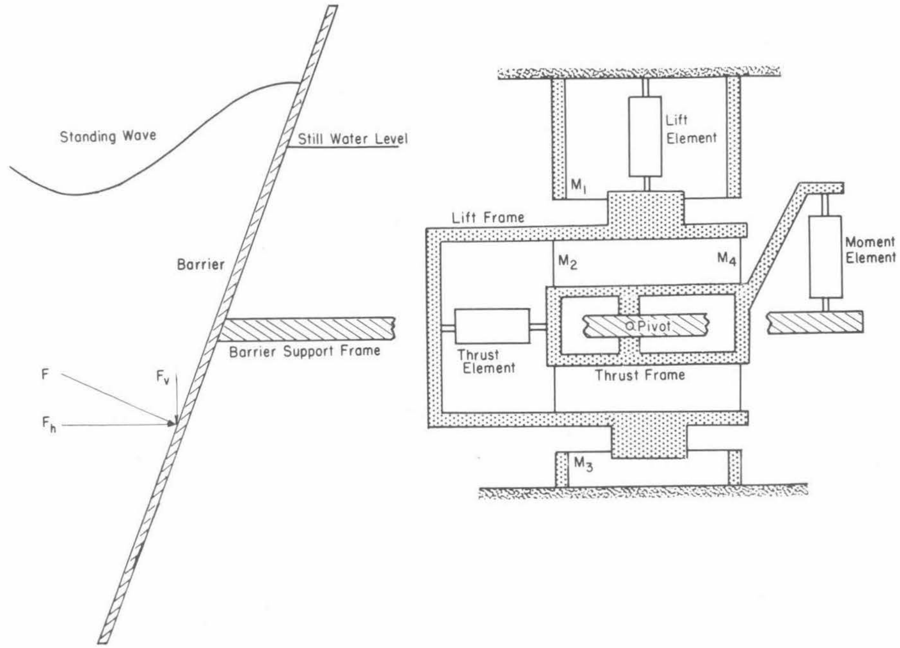

Fig. 4 - Schematic diagram of wave force balance

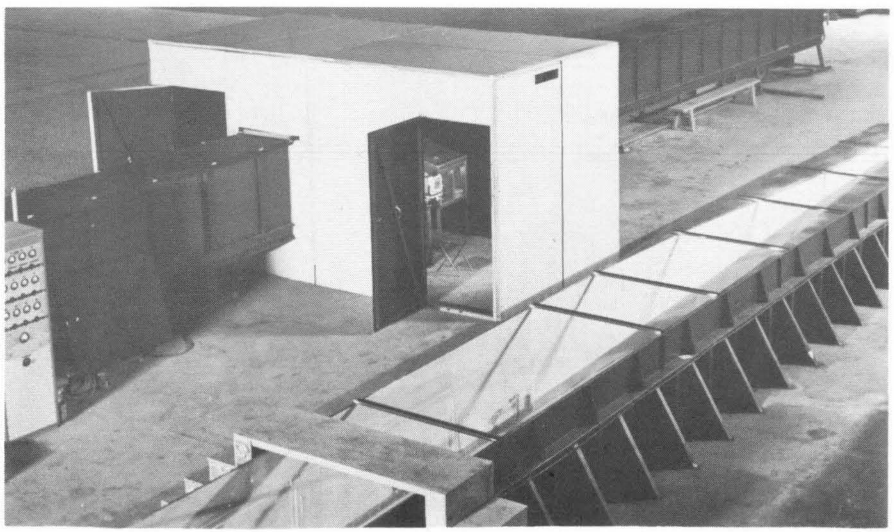

Fig. 6 - Darkroom for trajectory photographs

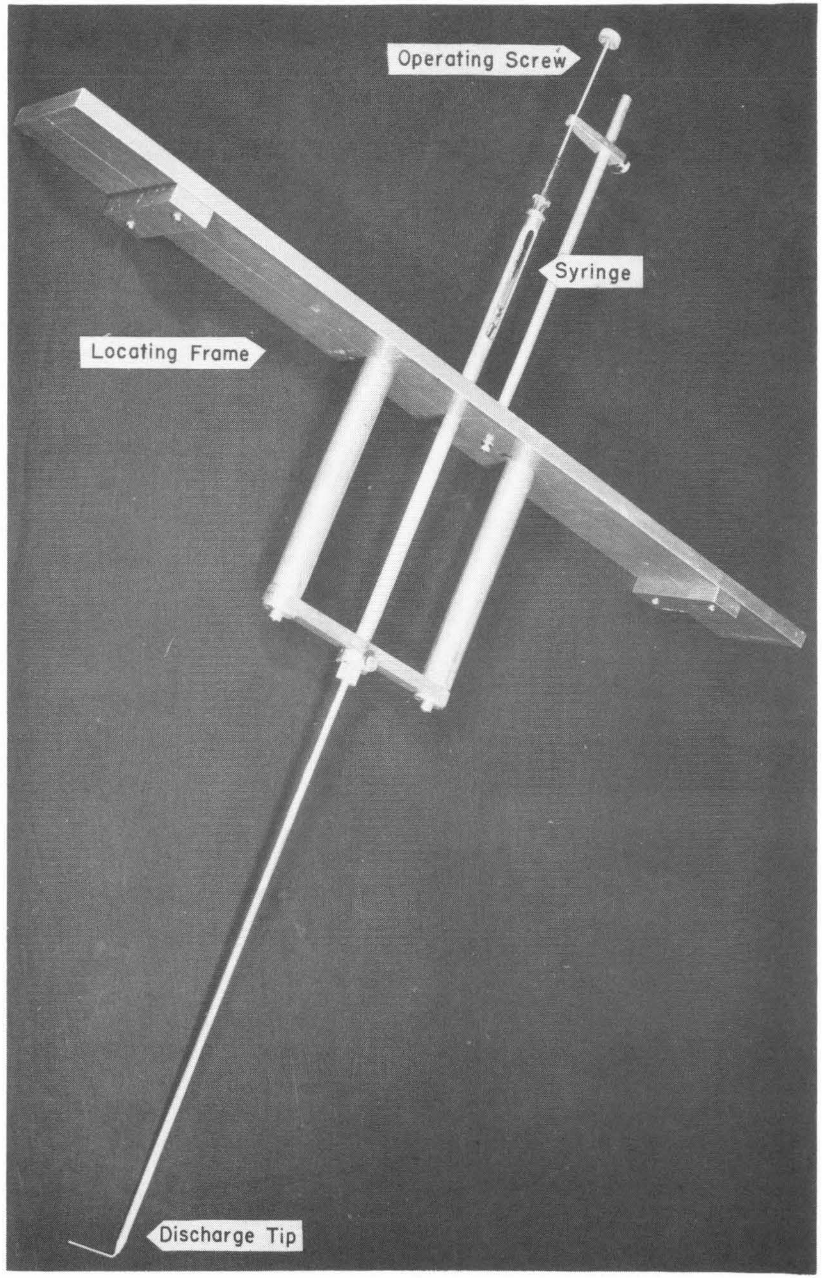

Fig. 5 - Globule injection assembly

It is believed that such experimental determinations of orbital parameters will be valuable for evaluating certain theoretical procedures which have been advanced for calculating the wave force on exposed structures such as piles.

R e f e r e n c e s

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